REAL OR VIRTUAL IMAGING SYSTEM WITH REDUCED GHOST IMAGING

REFERENCE TO PROVISIONAL APPLICATION

This application claims an invention which was disclosed in Provisional Application Number 60/131,320, filed April 27, 1999, entitled "NO GHOST FILTER". The benefit under 35 USC § 119(e) of the United States provisional application is hereby claimed, and the aforementioned application is hereby incorporated herein by reference.

FIELD OF THE INVENTION

The invention pertains to the field of virtual or real image display systems. More particularly, the invention pertains to a real image display system with a decreased ghost imaging effect.

BACKGROUND OF THE INVENTION

It is desirable in modern imaging display systems to provide images having good contrast that appear sharp and undistorted to the viewer. One of the major problems in presenting a clear image is that real, virtual, or infinity imaging systems generally employ curved mirrors and exhibit problems with secondary ghosting, that is, forming an additional image of the projected light source image at the point of observation. This occurs when outside light enters an imaging system and is projected as an additional ghost image near the focal point at which the primary image is projected and viewed.

Ghost image formation in a prior art imaging system 10 is illustrated in Figure 1. A primary image 12, *e.g.*, a target or CRT, is projected along a primary light path (PP) that includes a beamsplitter 14 and a curved mirror 16. A primary image 18 is formed as shown at a focal point FP_R outside the system. Outside light 20 entering system 10 traverses a secondary light path (SP) inside the imaging system, and due to a different angle of incidence is reflected at a different angle from mirror 16, focusing a ghost image 22 at a focal point FP_G

non-coincidental with FP_R. The result is poorer contrast and resolution in the primary image 18.

Another prior art approach is to include an absorptive beamsplitter for absorbing outside light entering the optical system. This technique is effective in decreasing the brightness of the ghost image, but it does not eliminate the ghost image entirely or even decrease it significantly, and the ghost image remains visible. A similar approach is to include high efficiency, anti-reflective coatings on optical system components, for example on the lens elements. This technique is again of limited effectiveness, and while decreasing ghost imaging, does not do so to a significant degree.

Another prior art approach as found in US Pat. No. 5,585,946 and shown in Figs. 2 and 2a is an imaging system 10a that includes a linear polarizer 30 and a quarter wave plate 32, positioned together as a window 34 into the system, a mirror 36, and a beamsplitter 38 inclined about 45 degrees, positioned in an on-axis configuration as shown. The quarter wave plate is an optical component producing a 45 degree polarization shift, while circularly polarizing unpolarized light. Fig. 3a shows the transmission of the primary imaging light within the imaging system. Figs. 3b and 3c show the transmission of outside light within the system as a percentage of the initial light source intensity transmitted by each indicated structure. The transmission of primary imaging light exiting window 34 is about 10.62 percent, for structures having characteristics similar or identical to those described below for the preferred embodiments of the present invention. As shown in Figs. 3b and 3c, unpolarized outside light entering the system through window 34 is polarized by linear polarizer 30, which is shown as horizontal polarization for purposes of discussion, and upon traversing quarter wave plate 32 becomes right circular. The light then passes through beamsplitter 38 (a 50 percent transmitting 50 percent reflecting-type, for purposes of discussion) twice, once before striking the mirror and again after reflection from the mirror, in the process transitioning twice between right and left-circular polarization. The configuration is effective in blocking all but 5.313 percent of the outside light that entered imaging system 10a. In the process, however, beamsplitter 38 phase-shifts the circularly polarized light, introducing an elliptical component into the light that prevents it from being entirely blocked

by polarizer 30, producing a viewable ghost image outside window 34 that degrades the optical resolution and contrast of primary image 18.

SUMMARY OF THE INVENTION

Briefly stated, a virtual or real image display system includes a primary image source for projecting a primary image from the start of a primary light path to an end of the primary light path at which the primary image is viewable, a mirror, a first beamsplitter positioned in the primary light path between the primary image source and the mirror, circular polarizing means for circularly polarizing a light beam positioned in the primary light path between the first beamsplitter and the mirror, and linear polarizing means for linearly polarizing light positioned in the primary light path between the end of the primary light path at which the image is viewable and the first beamsplitter, whereby outside light entering the system is substantially blocked before exiting the system, to thereby substantially eliminate ghost image formation caused by outside light sources.

According to an embodiment of the invention, a virtual or real image display system includes a primary image source for projecting a primary image from the start of a primary light path to an end of the primary light path at which the primary image is viewable, a mirror, a first beamsplitter positioned in the primary light path between the primary image source and the mirror, a quarter wave plate positioned in the primary light path between the first beamsplitter and the mirror, and a linear polarizer positioned in the primary light path between the end of the primary light path at which the image is viewable and the first beamsplitter, whereby outside light entering the system is substantially blocked before exiting the system, to thereby substantially eliminate ghost image formation caused by outside light sources.

According to an embodiment of the invention, a method of decreasing ghost images in a real or virtual imaging system includes the steps of projecting a primary image outside the imaging system, passing outside unpolarized light entering the imaging system through a linear polarizer to produce a first linear polarized light, beam-splitting the first linear polarized light, passing the beam-split, first linear polarized light through a quarter wave plate to produce a first circular polarized light, reflecting the first circular polarized light off a concave mirror to produce a second circular polarized light having a rotation opposite that of

the first circular polarized light, passing the second circular polarized light through the quarter wave plate to produce a second linear polarized light having an orientation opposite that of the first linear polarized light, beam-splitting the second linear polarized light, and blocking the beam-split second linear polarized light with the linear polarizer, thereby substantially eliminating ghost image formation in the imaging system due to outside light sources.

The imaging system positions the quarter wave plate between the beamsplitter and the mirror. This allows outside light to remain circularly polarized between the quarter wave plate and the mirror and avoids introducing an elliptical component to the outside light. The quarter wave plate converts the light back to linear polarized but now with the opposite orientation of the linear polarizer. The light impinges on the front window, and the linear polarizer effectively blocks substantially all the light, substantially eliminating ghost image formation from outside light sources.

Another advantage of the imaging system achieved by placement of the quarter wave plate behind the beamsplitter is, with the beamsplitter inclined, preferably about 45 degrees, outside light entering the system and linear polarized by the front window is more effectively reflected upward and out of the system by the inclined beamsplitter than are other orientations of light, e.g. unpolarized, circularly polarized, or elliptically polarized light. This greatly decreases the outside light intensity within the imaging system and further contributes to decreased ghost image formation.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a prior art imaging system.

Figs. 2 and 2a show a prior art imaging system.

Figs. 3a, 3b, and 3c show light transmission characteristics of the prior art system of Figs. 2 and 2a.

Fig. 4 shows an on-axis configuration of an image display system according to the invention.

Figs. 5a, 5b, and 5c show light transmission characteristics of the system of Fig. 4 according to the invention.

Fig. 6 shows an on-axis configuration of an image display system according to the invention.

Figs. 7a, 7b, and 7c show light transmission characteristics of the system of Fig. 6 according to the invention.

Fig 8 shows an of-axis configuration of an image display system according to the invention.

Figs. 9a, 9b, and 9c show light transmission characteristics of the system of Fig. 8 according to the invention.

Fig. 10 shows an off-axis configuration of an image system according to the invention.

Figs. 11a, 11b, and 11c show light transmission characteristics of the system of Fig. 10 according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The term "on-axis" as used herein is also intended to include imaging systems having a near on-axis configuration of optical components with respect to the light path within the imaging system, as should be readily apparent to one of ordinary skill in the art.

Referring to FIGS. 4 and 5a, a virtual or real image on-axis display system 100 includes a projected primary image 102, such as that produced by a cathode ray tube or an illuminated object, projected as a monochrome, black and white, or color primary light beam 103. The source object 102 is anything that reflects, transmits or emits light. Light beam 103 partially passes through and partially reflects from inclined beamsplitter 104, in a 50:50 percentage ratio as shown for a 50 percent transmitting/50 percent reflecting (50T/50R) type beamsplitter 104. Optionally, the ratio may be other than 50T/50R. Beamsplitter 104 includes a clear substrate 106, a beamsplitter coating 108 or any partially reflective coating, and an optional anti-reflective coating 110.

A reflected, unpolarized light beam 112 passes through a quarter wave plate 114, which has no effect upon light beam 112 because it is unpolarized, and then reflects from concave mirror 116. Quarter wave plate 114 includes a quarter wave layer 118 and preferably a clear substrate layer 120 on each surface of layer 118. Each layer 120 is preferably coated with an anti-reflective layer 122. Mirror 116, which can be spherical or aspherical, includes a substrate 124, a mirror coating 126, and a protective overcoat 128. After striking mirror 116, primary light beam 103 starts converging toward a focal point determined by the radius of curvature of mirror 116. Light beam 103 then passes through each of plate 114 and beamsplitter 104 a second time, the transmission being 50 percent through beamsplitter 104, and then through a linear polarizing window 130 that polarizes light beam 103 at about 10.6 percent of the original intensity. The light is shown as horizontally polarized Window 130 includes a clear substrate 132, a linear polarizer 134, and an optional anti-reflective coating 136. Optionally, an anti-reflective coating is also applied to surface 134. Primary light beam 103 then converges to form an image 138. The precise location of image 138 depends on the focal point or radius of mirror 116. FIG. 5a shows the percent transmittance of light beam 103 as it passes through optical system 100.

Referring to FIGS. 5b and 5c, transmission of outside light within imaging system 100 shows an unpolarized outside light beam 140 entering system 100 through linear polarizing window 130 and acquiring a horizontal polarization for purposes of discussion. Light beam 140 then passes through beamsplitter 104, retaining its horizontal polarization, and then through quarter wave plate 114 where it becomes right circular ("RC"). Light beam 140 then reflects from mirror 116, becoming left circular ("LC"), and becomes vertically polarized ("VP") after passing through quarter wave plate 114. Light beam 140 passes again through beamsplitter 104 after which it is substantially blocked by linear polarizer 130, preventing the outside light from exiting system 100 and thereby substantially eliminating this source of ghost image formation.

Referring to FIG. 6, an on-axis image display system 200 is configured similarly to image display system 100a with the major difference being that quarter wave layer 118 is positioned on beamsplitter coating 108 to form a combined beamsplitter/quarter wave plate

structure 141. As shown, layer 118 is positioned on a surface 143 of beamsplitter coating 108 facing mirror 116. FIG. 7a shows the transmission of imaging light through system 200, which despite some variations within the light path achieves the same or about the same percentage transmission. FIGS. 7b and 7c show the analysis of outside light entering system 200, again showing that aside from some variations along the light path attributable to the different relative positioning of the optical components and in particular structure 202, system 200 like system 100 is effective in substantially blocking outside light before exiting window 130 and substantially eliminating this source of ghost imaging.

Referring to FIG. 8, an on-axis image display system 300 is configured similarly to image display systems 100 and 200 except that it is an on-axis system, that is, optical components 104, 114, and 116 are positioned along a central axis that is normal or approximately normal to an axis on which window 130 is positioned and along which light exits window 130 and image 138 is projected. As shown in FIG. 9a, imaging light converging to form primary image 138 has substantially the same intensity level percentage-wise as in systems 100 and 200. FIGS. 9b and 9c show that outside light entering system 300 is as effectively blocked as with systems 100 and 200, substantially eliminating ghost imaging attributable to outside light sources.

Referring to FIG. 10, an off-axis image display system 400 has a similar configuration to that of image display system 300, with the exception that as in system 200 beamsplitter 108 and quarter wave plate 118 are combined into a single structure 402. Structure 402, however, differs from structure 141 of system 200 in that structure 402 includes a quarter wave layer 118 positioned on a side 406 of structure 402, which faces the mirror 116 and the window 130. This configuration is consistent with systems 100, 200 and 300 in the sense that quarter wave layer 118 is thus positioned between beamsplitter coating 108 and mirror 116. As shown in FIG. 11a, imaging light converging to form primary image 138 has substantially the same intensity level percentage-wise as in systems 100, 200, and 300. FIGS. 11b and 11c show that outside light entering system 400 is again effectively blocked, substantially eliminating ghost imaging attributable to outside light sources.

Imaging systems 100, 200, 300 and 400 optionally include a second beamsplitter 142 (shown in phantom), preferably a 50T/50R beamsplitter, inclined preferably about 45 degrees with respect to a monochrome, black and white, or color secondary light beam 144 projecting a secondary image 146 (shown in phantom), producing a viewable secondary image 148 at or near primary image 138. This additional beamsplitter 142 allows a second image 148 to be projected at a different plane than image 102.

Imaging systems 100, 200, 300 and 400 optionally include one or more additional monitors 150 for projecting one or more additional images, such as, for example, one or more background images. The background image will appear as a virtual image located within the system. The advantage of a background image is that it allows a second plane of data or images to be presented behind the primary image.

Comparison

Without being bound by theory, it is believed that in prior art systems utilizing a configuration as in or similar to that of the Comparison test, the beamsplitter's off-axis angle of incidence with respect to the image light source and optical transmission path produces an elliptically-polarized component to circularly-polarized light incident on the beamsplitter that is not fully blocked by the front polarizer and that results in ghost image formation. It is standard knowledge within the optical industry that circular polarization becomes elliptical when passing through a substrate that has an angle of incidence other than normal.

In contrast, the present invention, by placing the quarter wave plate behind the beamsplitter with respect to the mirror, does not circularly polarize the outside light until after it initially passes through or reflects off the beamsplitter, after which the quarter wave plate introduces a circular polarization component to the light, and then removes the circular polarization component during the outside light's return path and before it again passes through or reflects from the beamsplitter, thereby substantially decreasing the elliptically polarized component and substantially decreasing ghost image formation.

The placement of quarter wave plate 114/118 between beamsplitter 104/118 and mirror 116 avoids the undesirable introduction of an elliptical phase shift into the outside light source light beam 112 as it traverses the light path by passing it through quarter wave plate 114/118. As circular polarized light passes through a glass substrate at an angle of incidence of other than normal, such as 45 degrees, the circular beam strikes the substrate at different positions within it circular path and the speed of the light is slowed as it passes through the substrate. The resulting circular polarization is distorted as it exits the substrate and becomes elliptically shaped. After reflecting off the curved mirror surface, the left elliptical polarization becomes right elliptical and does not return to pure circular polarization as it passes back through the beamsplitter substrate on its return path. In the No-Ghost configuration, the polarization is linear until after the beam passes through the inclined beamsplitter substrate, and therefore the angle of incidence will not affect the polarization. By circularly polarizing the light after the beam passes through the beamsplitter, the elliptical condition will never occur.

Accordingly, it is to be understood that the embodiments of the invention herein described are merely illustrative of the application of the principles of the invention. Reference herein to details of the illustrated embodiments are not intended to limit the scope of the claims, which themselves recite those features regarded as essential to the invention.